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INFLUENCE OF ENVIRONMENTAL CONTEXT ON MOTOR IMAGERY QUALITY: AN AUTONOMIC NERVOUS SYSTEM STUDY

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Abstract. This study was devised to evaluate the effect of the environmental information context on mental representation of a complex motor skill. Regional and national table tennis players were asked to perform a forehand topspin shot after an experimenter had served; during imagery sessions, they had to represent mentally the same sequence: 1) neutral imagery was conducted without information provided by reference to table-tennis, 2) context imagery included influences of the appropriate environmental context, wearing sports clothes, handling the table tennis paddle, hearing ball rebounds. Results evidenced that subjects had greater difficulty in building up a mental representation of the sequence in a neutral environment than with context imagery: longer and higher neurovegetative responses, closer to those recorded during actual movement, were observed in the context imagery modality than in the neutral imagery modality. Environmental context in which mental imagery of movement is performed could thus facilitate a subject's ability to build up mental simulation of a motor act.

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Key words: Mental rehearsal - Context imagery - Table-tennis - Autonomic nervous system

Introduction

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Motor Imagery (MI) requires the building up of a mental representation of motor performance without concomitant production of muscular activity normally required for acting [9]. Motor imagery can thus be defined as a dynamic state during which a subject simulates an action mentally without any body movement. It is now well known that common neural substrate underlie perception and MI. Several studies have confirmed structural and functional analogy between MI and perception [23,27]. Similarly, during MI, common processes involved in preparing action (planning and programming) are activated [5,21,31].

Several studies had demonstrated that MI helped to improve motor task performance [13,14]. Yue and Cole [36] showed that muscle strength increased after MI training. According to this study, increase in strength did not occur primarily as a result of changes at the execution level of the motor system but as neural changes at higher planning and programming levels of the motor system. Motor representations of acting and imaging are only differentiated by the circumstances in which they are generated [21]. According to Denis [9], combining mental and physical practice was more efficient or at least equal to physical practice to improve motor skills, when there is no decrease in total physical practice time. Moreover, MI would be more effective in closed skills than in open skills: imagery would be easier when the execution of the skill takes place in a similar and monitored environment, without the influence of an opponent [9,19]. However, many papers have investigated the role of MI in open-ended skill improvement. In soccer, a significant performance improvement was observed in both skilled and novice players in the imagery group [3]. In table tennis, Zhang *et al.* [37] showed the effect of MI training on performance enhancement with children: young athletes who used MI experienced significantly greater improvement in the accuracy and technical quality of their shots than the control group. Lejeune *et al.* [26] found that table tennis players who used mental training associated with physical and observational learning techniques did improve, qualitatively and quantitatively, the execution of both forehand and backhand counterattack shots.

Direct methods based on central nervous system recordings (such as fMRI or TEP) could not be used in the field as they are non-ambulatory methods. Autonomic Nervous system (ANS) activity recording is well adapted in studying mental processes in the field [4,20]. It is now well-known that peripheral ANS effectors are activated by MI [2,22,25]. Measuring cardiac and respiratory activity during mental simulation of locomotion at increasing levels revealed a co-variation of heart rate and pulmonary ventilation with the degree of imagined effort [6,7]. A strong increase in ventilation and a significant elevation in systolic blood pressure were also observed when subjects imagined lifting dumbbells [34], whereas Wuyam *et al.* [35] showed that ventilatory effects were specific to exercise imagination. The greater likelihood of generating ventilatory responses in highly trained athletes, experienced in "rhythmic" sports, may be related to awareness of breathing and its role in exercise imagination strategy. Deschaumes-Molinaro *et al.* [10,11] found the same pattern of ANS responses during actual shooting, mental concentration before shooting and MI of shooting. More recently, Roure *et al.* [33] demonstrated that mental rehearsal of a volley-ball task elicited a specific ANS pattern which was associated with the best results. However, the effect of the environmental context in which mental imagery is carried out has never been questioned.

Several studies had evidenced that sportsmen are used to carrying out imagery during competition (just before competing) rather than during practice [1,18,29]. Nevertheless, the context in which subjects should train is a research area that has received too little attention in sport. The characteristic of mental training must be close to those regarding execution [32]. Then, could the environmental context help subjects to build up mental representation of a motor sequence? The aim of this study was thus to question context impact on MI in an open skill. Mental imagery is hypothesised to be more effective when performed in a context close to actual practice situations rather than in a neutral environment. ANS response patterns recorded during Context Imagery are expected to be closer to those observed during actual practice than those observed during Neutral Imagery.

Materials and Methods

Participants and procedure: A table tennis sequence (returning serve by a forehand attack) was chosen as the experimental paradigm. Thirteen table tennis players, aged between 16 and 30 (mean 24.5, standard deviation 3.4) took part in this experiment. They were healthy volunteers playing table tennis at a regional or national level (at least 10 years of experience). They were asked to both perform and imagine a forehand topspin shot after an experimenter had served. MI sessions were performed under two distinct conditions:

- Neutral imagery (NI): individual sessions were performed in an environment without any information from the table tennis context. Subjects were phonically isolated, seated in a comfortable chair and had to represent the table tennis sequence.

- Context imagery (CI): subjects had to represent the same motor sequence, in a situation close to the competition context: mental representation was carried out while subjects wore sports clothes, handled their paddle while standing in front of the table. Subjects had to start their mental representation when the experimenter started to bounce the ball on the table, just before serving. Such bouncing is commonly used during competition by all table tennis players as a signal of preparing the exchange.

Subjects performed 15 real trials and 10 MI trials of each modality. Each trial was separated from the next by a rest period which was never less than 20 s. No body movement took place during motor imagery (Neutral and Context imagery). Three ANS variables (Skin Resistance, Skin Temperature and Instantaneous Heart Rate) were recorded continuously while subjects performed actual forehand topspin shots and motor imagery in a first-person process (Neutral or Context). Sensors were placed on subjects' non-dominant hands and heart rate was recorded by a thoracic strap, 15 to 20 min before the beginning of the experiment, in order to avoid disturbance and to record a stable baseline. Ambient temperature was maintained within a variation of 2°C.

Before the experiment, subjects completed the Movement Imagery Questionnaire individually (MIQ, [17]) in a quiet room close to the laboratory. The MIQ is made up of 18 items known to evaluate individual differences both in visual (9 items) and kinaesthetic (9 items) movement imagery. Each item corresponds to a specific movement which is precisely described, and each individual is asked to complete the questionnaire by imagining the same movement. A final value is assigned from a 7-point rating scale regarding the difficulty associated with representing each movement mentally.

Data acquisition: Instrumentation was designed by the Biomedical Microsensors and Microsystems Laboratory of the French National Institute of Applied Sciences [12]. Signal sampling was carried out by a 16-bit data acquisition card (ADAC 5508HR) at a frequency of 10Hz. Signals were both recorded by a potentiometric D.C. recorder (YTSE 460 type BBC) for rapid visual inspection of recordings and by a microcomputer. The apparatus was fitted with an event-tracer and an automatic synchronization appliance which cancelled out temporal differences between the markers. A special software package designed for data processing [30] made it possible to calculate all indices. It featured other utilities such as the amplification or attenuation of signals and zooming. Digital signal-processing was designed and added to the software to make the processing of all varieties of artefacts possible and to filter random noise whenever present in the recorded signal.

Skin Resistance (SR): SR was recorded using two 30mm² unpolarizable Ag/AgCl electrodes (Clark Electromedical Instruments, Ref. E243). Resistance was measured with 15µA current (current density=0.5µA/mm²) and a conductive paste was used to improve skin/electrode contact. Sensors were placed on the second phalanx of the second and the third digit of the non-dominant hand, held by adhesive tape. As response amplitude depends on the pre-stimulation value [15], a more reliable index is defined by the time during which the subject remains under stimulation influence without referring to the initial value (or tonic level). This Ohmic Perturbation Duration (OPD) index is measured at the beginning of the sudden drop which occurs simultaneously with the stimulation initiation and ends when recovery shows no fluctuations. It is thus possible to estimate the time during which the subject is under stimulation effect.

Skin Temperature (ST): ST was measured by a low thermal inertia thermistor (Betatherm, Ref. 10 K3 MC D2). The 4mm² sensor was fixed to the middle of the palm of the non-dominant hand using a non-caustic glue. A variation of about one hundredth of a degree could be detected under such conditions. The active structure is 0.03mm² and the thermistor is secured by glue fixation within a catheter (mechanical protection, diameter=0.8 mm). Error linearization on temperature measurement is less than 0.04°C [8].

Instantaneous Heart Rate (IHR): IHR was recorded from three large silver electrodes (8cm² surface) placed in the precordial position. The D2 derivation signal (between two consecutive R waves) was electronically processed and delivered in the form of instantaneous heart frequency, expressed in beats per minute (bpm). The smallest appreciable variation was 0.5 bpm and the calibrated scale ranged between 0 and 200 bpm. The IHR signal was directly extracted from the electrocardiogram signal at sensor level. Therefore, the IHR was an analogous signal. Data acquisition was carried out at 10Hz on this analogous signal. The time of occurrence of the R-waves could thus be determined. According to the cardiotachometer lag, a remedial device was fitted to the recording system.

Statistical analysis: Result processing of the experimental population was completed by intra-subject analysis. Due to the number of subjects and as distribution was not gaussian, data were processed by a non-parametric test to compare phasic activity (response amplitude and duration) according to each experimental modality. Two-by-two comparisons were made using the Wilcoxon test for paired groups. Independent groups were compared by the Mann-Whitney test. According to the MIQ, the criterion for a high imager was a score of at least 1 SD below the mean. Similarly, low imagers were those scoring more than 1 SD above the mean [16].

Results

Mean MIQ scores (standard deviation -SD-) were 17.92 (4.79) and 29.92 (9.14) in the visual and kinaesthetic modalities, respectively.

Short SR responses were recorded during NI whereas long duration was observed during CI (Z=-1.99, p<0.05). Responses were longer during actual performance in comparison with CI or NI (Z=-2.97, p<0.01 and Z=-3.04, p<0.01, respectively). IHR responses showed a decreasing value (bradycardia) during mental imagery whereas tachycardia was observed during actual practice. No significant difference was evidenced between CI and NI in bradycardia duration. Response amplitude was stronger when mental imagery was performed during CI when compared to NI (Z=-2.97, p<0.01). IHR response amplitude recorded during actual practice was higher than those observed during both imagery conditions (Z=-3.18, p<0.001). Each imagery condition was thus characterised by a specific ANS response pattern of SR and IHR. Differences in ANS response during imagery sessions and actual practice are summarised in Fig. 1 and illustrated by Figs. 2 and 3.

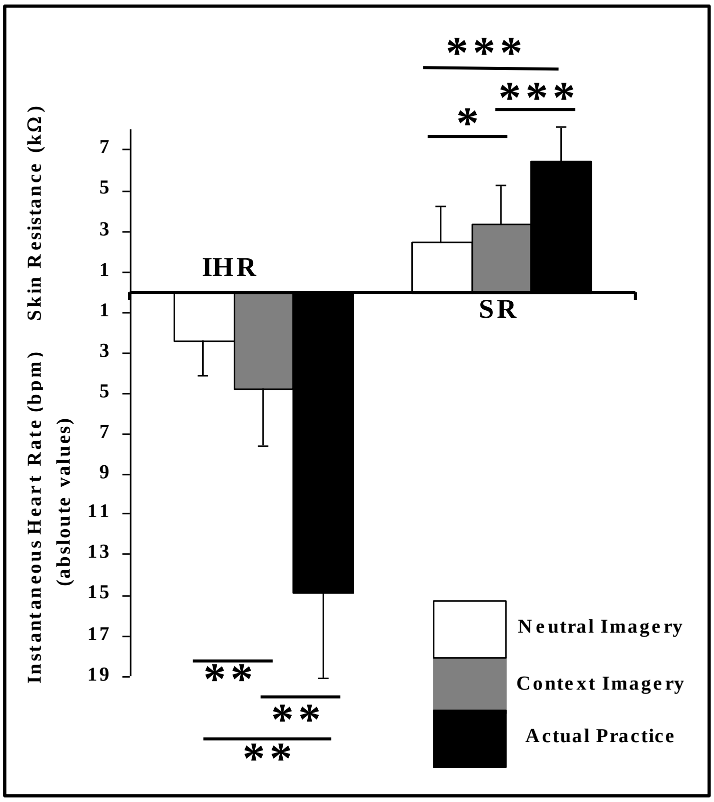

Fig. 1
Phasic activity during Actual Practice (AP), Context Imagery (CI) and Neutral Imagery (NI)

Longer Skin Resistance (SR) responses were recorded during AP when compared to those recorded during both imagery conditions ($p<0.001$). Longer Skin Resistance responses were also observed during the CI session in comparison with the NI session ($p<0.05$). Similarly, amplitude (absolute values) of Instantaneous Heart Rate (IHR) responses was higher during AP than during both imagery conditions ($p<0.01$) and higher during CI than during NI ($p<0.01$).

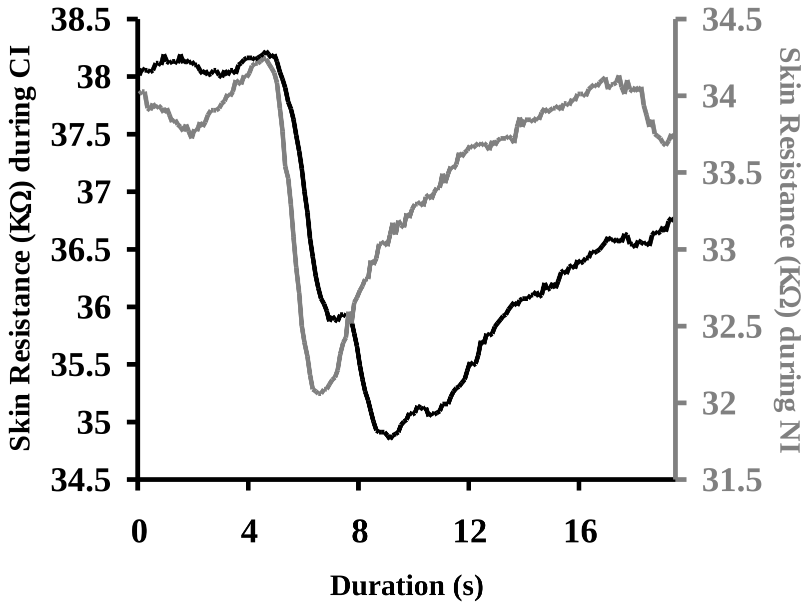

Fig. 2
Skin resistance response (ohmic perturbation duration) during Context Imagery (CI) and Neutral Imagery (NI)
The ohmic perturbation index is defined as the duration of the SR perturbation elicited by stimulation. It is considered the time period during which subjects remain under the dependence of the stimulus. A longer duration was observed during CI ($p<0.05$) when compared with NI. There were thus longer responses when subjects simulated the motor action in a context close to a competition environment.

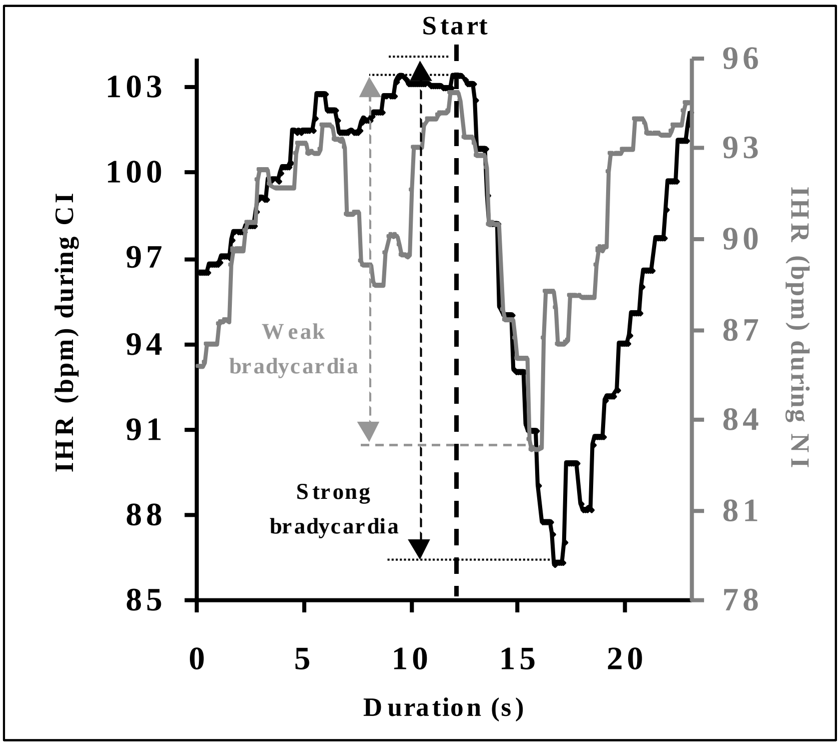

Fig. 3
Instantaneous Heart Rate (IHR) response between Context Imagery (CI) and Neutral Imagery (NI)
Bradycardia, related to focused attention, was recorded when subjects simulated the motor sequence mentally. No difference was evidenced between the two imagery conditions when response duration was considered. Conversely, response amplitude was stronger when motor imagery was performed in an environment close to the competition context ($p<0.01$).

With reference to ST duration and amplitude, no significant difference was observed between Imagery conditions. Increase in duration ($Z=-3.18$, $p<0.001$) and amplitude ($Z=-3.18$, $p<0.001$) was evidenced during actual practice when compared to both CI and NI.

Discussion

In this experimental group, the mean MIQ score evidenced higher visual imagery ability than kinaesthetic imagery ability (17.92±4.79 and 29.92±9.14, respectively). These results are in compliance with many studies, with the exception of sporting tasks, such as figure skating or diving [16,28], such tasks requiring a highly developed kinaesthetic sense. Depending upon table tennis requirements, although subjects use kinaesthetic information to control movement and regulate posture, visual search strategies are thought to be more determinant than kinaesthetic information to allow reliable prediction of ultimate event outcome.

During shooting events, similar ANS responses between concentration, imagery and execution phases were recorded [11]. Mental activity during the concentration phase, attested by autonomic activity, was close to that recorded during the imagery phase. In the present study, different response patterns were evidenced during imagery sessions and actual practice: bradycardia were recorded during MI whereas tachycardia were observed during actual practice, due to the movement. Furthermore, longer ohmic perturbation duration (OPD) was associated with higher and longer ST and IHR response amplitude and duration. These results indicate that subjects have difficulty in clearly building up mental representation of movement: ANS responses during mental imagery did not match those observed during actual practice. These findings consequently evidence a workload decrease when subjects were required to build up mental representation of the task. However, longer skin resistance responses were evidenced during CI in comparison with those recorded during NI. IHR response amplitude was also higher during CI than during NI. Subjects can therefore more easily build up mental representation of the motor act when mental training is performed with appropriate environmental stimulation.

Lacey and Lacey [24] correlated bradycardia with an increase in focused attention, while subjects were waiting for an expected stimulation. In the present study, differences in IHR response amplitude indicate that focused attention is more important during CI than NI. Thus, mental activity seems to be more easily performed when subjects have to build up mental representation with appropriate environmental stimulation (tactile and auditory).

It has been shown that mental imagery enhances performance, even in open skills [32,33]. Present results show that environmental conditions, in which mental representation is performed, can facilitate a subject’s ability to imagine the motor sequence. In this study, subjects are not shown to be high imagers. Such a result is not surprising: this activity is an open skill in which subjects do not traditionally follow imagery training sessions. Therefore, environmental conditions, particularly tactile, proprioceptive and auditory information, may help them to visualise and feel sensations which are correlated with those recorded during actual practice. Such a finding could then be extended to athletes who are not in the habit of performing mental imagery during training sessions. However, it would be useful to test this hypothesis with subjects who are considered high or low imagers: adequate environmental conditions, i.e. conditions close to those occurring during actual practice, may help athletes to mentally represent situations close to those observed during a competition. Thus, future research should investigate phasic responses recorded during CI and their relationships to those recorded during NI when subjects represent motor acts easily or with great difficulty.

In conclusion, imagery sessions performed in an appropriate stimulation context are more efficient than imagery sessions in neutral conditions. These environmental parameters may help subjects in representing the situation. Mental practice could thus be a useful tool associated with physical training [32].

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